भारतीय मानक
Indian Standard

IS 9447 : 2023

नहरों में रिसाव का विश्लेषणात्मक विधि द्वारा आंकलन — दिशानिर्देश

(पहला पुनरीक्षण)

Assessment of Seepage Losses from Canals by Analytical Methods — Guidelines

(First Revision)

ICS 93.160

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January 2023 **Price Group 10**

Canals and Cross Drainage Works Sectional Committee, WRD 13

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Canals and Cross Drainage works Sectional Committee had been approved by the Water Resources Division Council.

Irrigation project design, operation and maintenance, and canal lining works, require accurate and economical measurement of seepage rates. The possible benefits from canal lining are saving in water, elimination of waterlogging, and reduction in maintenance cost. Hence, correct assessment of seepage loss in unlined canals is very important for evaluation of benefits from lining and field observations

The loss of water by seepage from unlined canals in India generally varies from 0.3 to 7.0 m^3/s per 10^6 m^2 area depending on the permeability of soil through which the canal passes, location of water table, distance of drainage, bed width, and side slope and water depth inside the canal. In addition, flow velocity, soil, water temperature, atmospheric pressure and stratification of the underlying soil also affect the seepage rate.

The seepage losses from unlined canals can be calculated by analytical methods or determined by direct measurements on the channels. The analytical calculations of seepage losses based on coefficient of hydraulic conductivity of soil and the boundary conditions of the flow system are of particular value for the canals which are in the planning stage. The methods of direct measurement of seepage losses are applicable to the existing canals.

Currently, the methods accepted for direct measurement of seepage losses from existing canals are the methods of ponding and inflow-outflow. In addition, other special methods such as tracer technique, seepage meter, electrical logging or resistivity measurement, and piezometric surveys are also available. The ponding and inflow-outflow methods are applicable regardless of canal or soil conditions. The seepage meter cannot be used where the channel has rocky bottom or heavy weed growth and the tracer technique is best suited to canals in homogeneous and isotropic formations.

The standard was published in 1980 and the first revision of the standard has been brought out to correct the editorial mistakes and bring out the standard in latest style and format of Indian standards. In the first revision, the notations have been updated.

The composition of the committee responsible for the development and approval of this standard is listed at Annex B.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

ASSESSMENT OF SEEPAGE LOSSES FROM CANALS BY ANALYTICAL METHODS — GUIDELINES

(First Revision)

1 SCOPE

1.1 This standard provides guidelines for assessment of seepage losses in open channels by analytical method.

1.2 This standard is applicable in open channels along watershed divide and which are not normally subject to recharge from ground water.

2 NOTATIONS

The following symbols are used in this standard:

A = function of canal geometry, obtained from Fig. 15, and

b = width of channel bottom in θ–plane (m),

B = width of channel bottom in z–plane (m),

B_s = width of channel water surface in z–plane (m),

F = seepage function,

h = drop between channel and drain water levels (m),

H = water depth of channel (m),

k = coefficient of permeability (m/s),

L = drainage distance from water line of the channel (m),

m = $\cot \pi\alpha$

q = volume rate of seepage per unit length of channel (m^3/sec/m),

t = assumed variable varying from 0 to γ,

T = depth of pervious medium from drain bed (m),

$\pi\alpha$ = canal side slope angle with horizontal in z–plane (radians),

$\pi\alpha'$ = canal side slope angle with horizontal in θ plane (radians),

σ, β, γ = transformation parameters (dimensionless),

x,y = coordinates,

θ = $\theta_1 + i\theta_2'$ = complex variable representing Zhukovsky's function,

ϕ = potential function,

3 ANALYTICAL METHOD

3.1 The seepage losses from unlined canals depend on canal dimension, permeability of subsoil, distance of governing drainages and difference in water levels of canal and drainage. Initial seepage losses are high due to steep gradient, but as the subsoil becomes saturated the gradients flatten and ultimately stabilize.

3.2 Analytical solutions are available for evaluating seepage losses from canals under steady conditions for the following cases.

a) Canals located in medium extending up to infinite depth with shallow water table;
b) Canals located in medium extending up to finite depth with shallow water table; and
c) Canals located in medium extending up to infinite depth with deep water table.

The solutions given here are for homogeneous and isotropic medium. The flow is assumed to be laminar and hence follows Darcy's law.

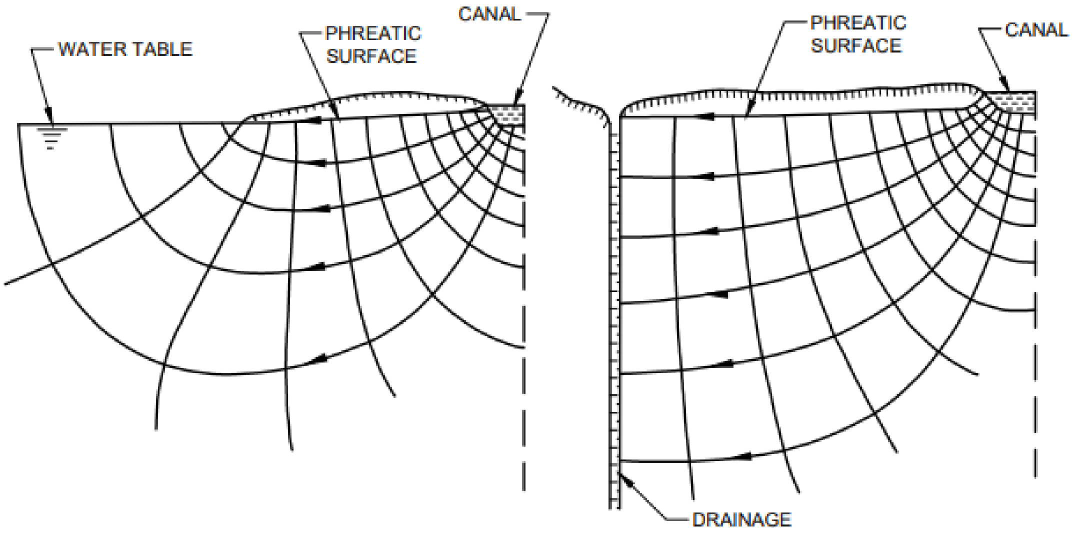
3.3 The seepage from canal for cases indicated in (a) and (b) above flows to the drains in a direction approximately transverse to the direction of flow in canals and drains. The lines of flow from canal meet the drains at various dopes, depending on the cross section of the drain. The problem can be simplified to the following two extreme conditions (*see* Fig.1).

3.4 Horizontal Drainage

If the drain is shallow and wide, the stream lines of seepage flow from the canal may join the bottom of the drain at various points along its width as shown in Fig. 1 (A). In this case the bed of the drain represents an equipotential surface.

3.5 Vertical Drainage

3.5.1 If the drain is narrow, the seepage might enter it from both sides of the drain as shown in Fig. l (B). In this case the streamlines of seepage flow from canals on both flanks of drain would reach the drain in a horizontal direction, and a vertical plane along the line of flow of the drain may be considered to represent an equipotential surface. Such a flow situation may also arise when seepage occurs from a canal to a shallow water table. Far away from the canals, in the zone of uniform flow of ground water, the streamlines would be almost horizontal and the equipotential lines nearly vertical. Such an equipotential line may be considered to represent a vertical drain.



Horizontal Drainage

Vertical Drainage

FIG. 1 SEEPAGE FROM CANALS TO DRAINAGES

3.5.2 In practice the flow may not fall distinctly into either horizontal or vertical drainage but may be a combination of the two. In such cases a fair idea of the flow would be obtained by a study of the two extreme cases.

3.5.3 The solution of the problems is obtained by conformal mapping by transforming the physical plane on to rectangular flow field through intermediate fictitious planes. The derivations obtained are rather involved. However, the results are plotted in the form of curves which make it easy to obtain the seepage discharge and the phreatic surface for any canal.

4 COLLECTION OF DATA

4.1 In order to assess the seepage losses and the profile of water table on either side of the canal, the following data should be collected:

a) Bed width of canal;

b) Water depth inside the canal at full supply;

c) Side slope of the canal;

d) Distance of the governing drainage on either side of the canal;

e) Dry season and rainy season water levels of drains on either side;

f) Coefficient of permeability of the subsoil to be determined in field by a suitable method such as pumping out test; and

g) Profile of the subsoil to find out effective impermeable layer, if any, exists and its depth.

4.2 The drainages at which the above information to be collected shall depend on the order of variations in values of above parameters. Where variation in the subsoil permeability, drainage distance and difference in water levels of the canal and drain is large, the data should be collected at a spacing of 2 km. Otherwise, the data may be collected at a spacing of every 5 km to 10 km spacing.

5 ESTIMATION OF SEEPAGE LOSSES AND PHREATIC SURFACE

5.1 Canals Located in Medium Extending Up to Infinite Depth with Shallow Water Table

5.1.1 Procedures for horizontal and vertical drainage conditions are given below.

5.1.1.1 *Horizontal drainage* — Knowing the dimensions of the system in the physical plane, the two parameters β and γ are determined as follows:

a) The bed width B, the slope angle $\pi\alpha$ (in radians), the distance up to drainage L, the water depth inside the canal H and the difference in water levels of the canal and drainage h are recorded for the subject case (*see* Fig. 2).

b) Figure 3 can be used to obtain values of transformation parameters of β and γ. The use of figure requires the values of b/H, L/H and α are bed width and side slope of the channel in an intermediate plane. To start with, the initial values of b and α' may be taken as equal to β and α respectively and values of β and γ be obtained from Fig. 3. The values of b/H and L/H are represented along ordinate and abscissa of the graph respectively, for values of α' equal to 0.15, 0.25 and 0.35. The scales corresponding to the value of α' are used for determining the values of β and γ.

c) Figure 5 presents graphically the relationship between α and α' and Fig. 6 presents the relationship between B and b. With the known values of h/H, α, β and γ, the values of α and b/H are obtained from Figs. 5 and 6 respectively.

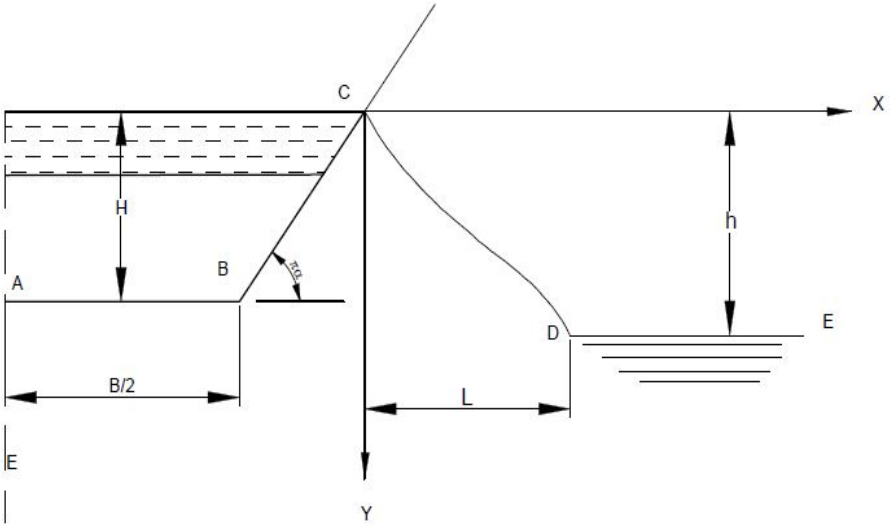
d) With these values of b/H and α, the approximate values of β and γ are determined from Fig. 3 and the process is repeated until difference/variation in the values of β and γ from one trial to another is negligible. This condition is normally achieved within three trials.

Seepage discharge: Knowing β and γ, the seepage discharge per unit length of channel q in terms of kh is obtained from Fig. 7.

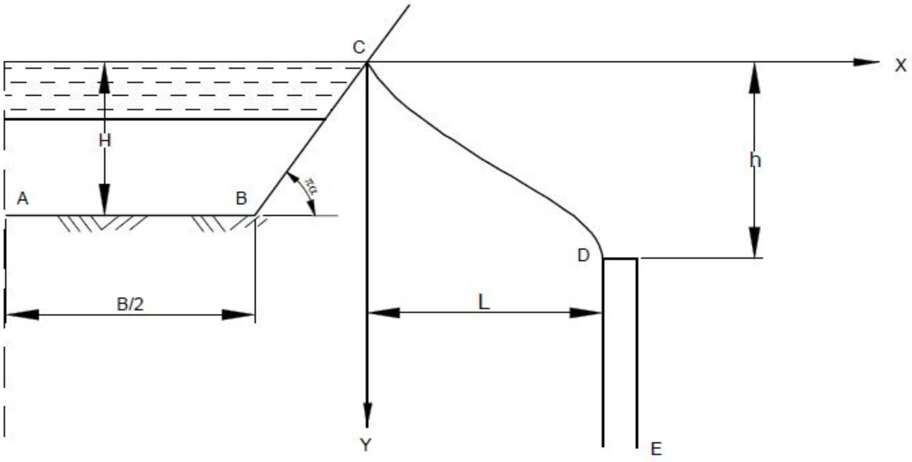
Phreatic surface: Figures 3 and Fig. 8 can be used for obtaining x and y coordinates of the phreatic surface. For an assumed value of variable t between zero and γ, a ratio t/γ is determined. With this value of t/γ and known value of β/γ the value of y/h is obtained from Fig. 8. For the same value of t and the known value of β the value of x/H can be obtained from Fig. 3 by replacing L by x and γ by t in the figure.

5.1.1.2 *Vertical drainage* — The procedure with vertical drainage is similar. For vertical drainage, Fig. 4 is used for determining β, γ and x/h.

The seepage discharge and phreatic surface profile are determined separately for either side of the canal. The total seepage is obtained by adding the seepage discharge estimated for either side.



(A) Horizontal drainage



(B) Vertical drainage

FIG. 2 PHYSICAL PLAN OF DRAINAGE

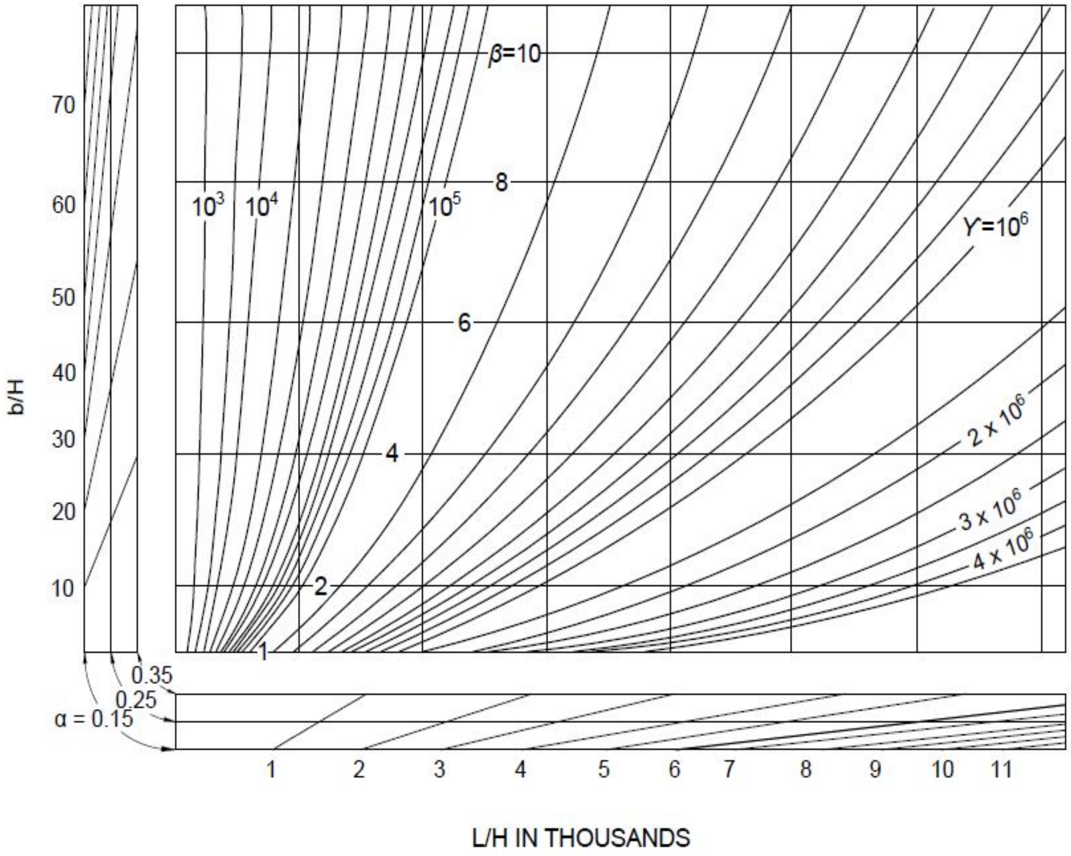


FIG. 3 VALUES OF β AND γ IN HOROZONTAL DRAINAGE

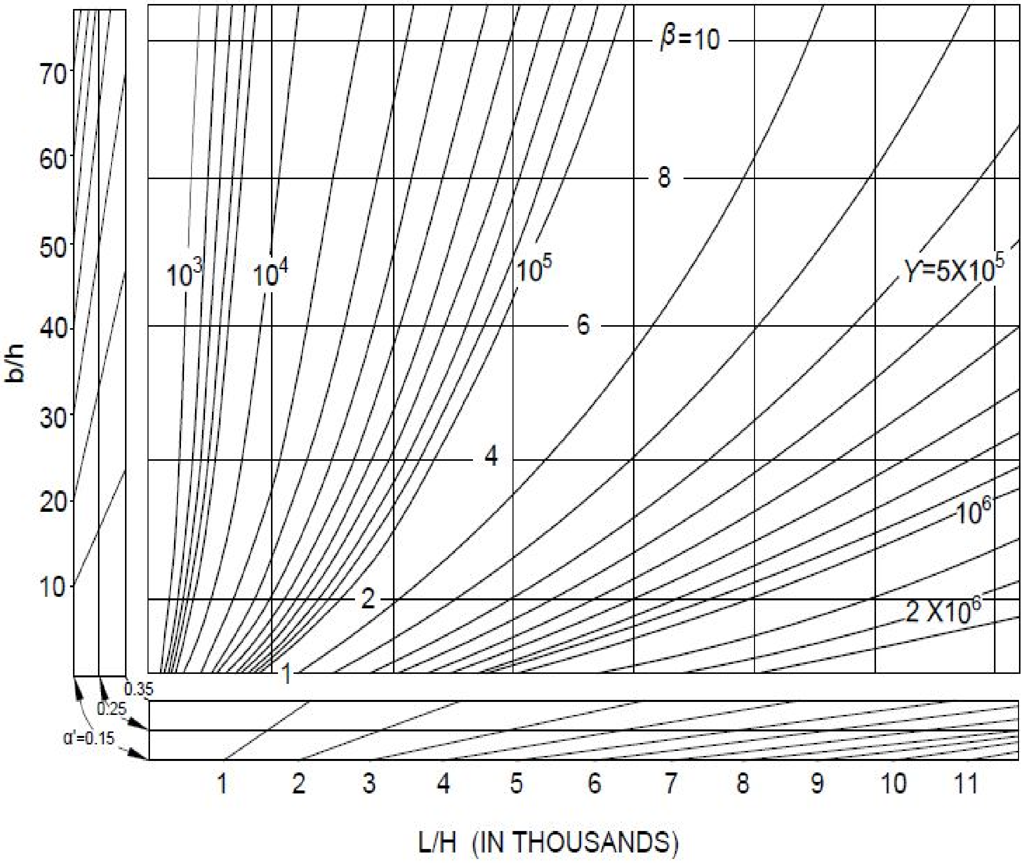


FIG. 4 VALUES OF β AND γ IN VERTICAL DRAINAGE

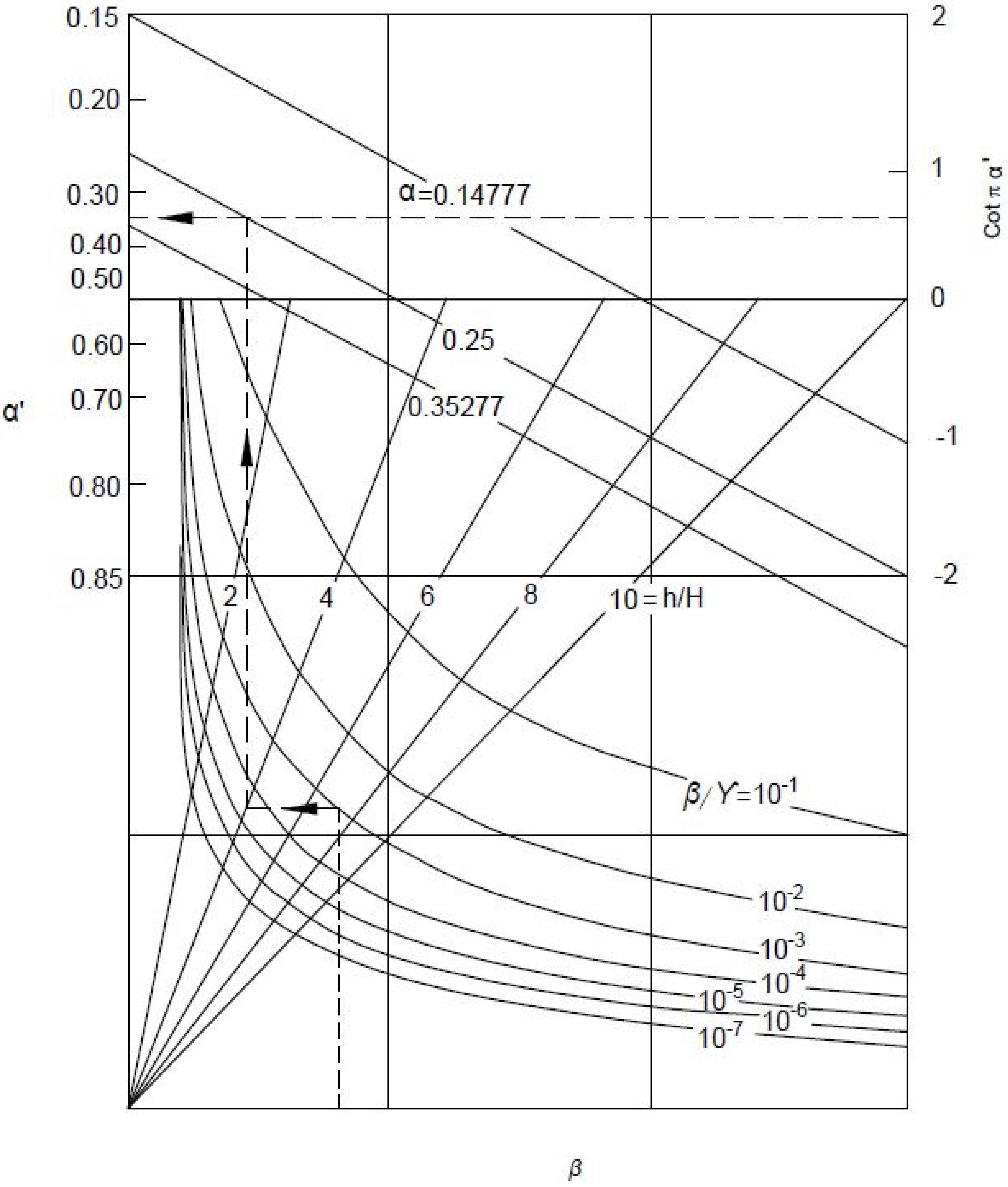


FIG. 5 RELATION BETWEEN α AND α'

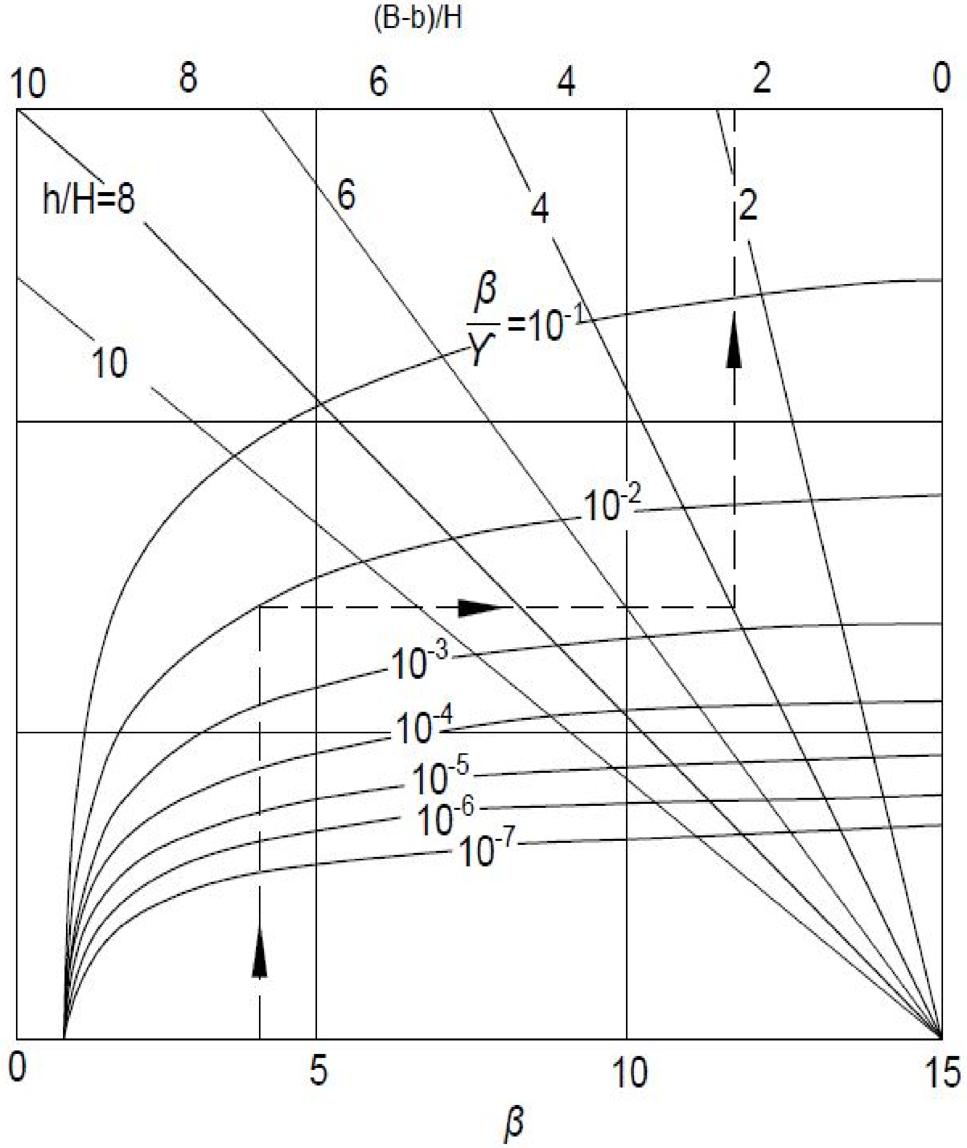


FIG. 6 RELATIONSHIP BETWEEN 'β' AND 'b'

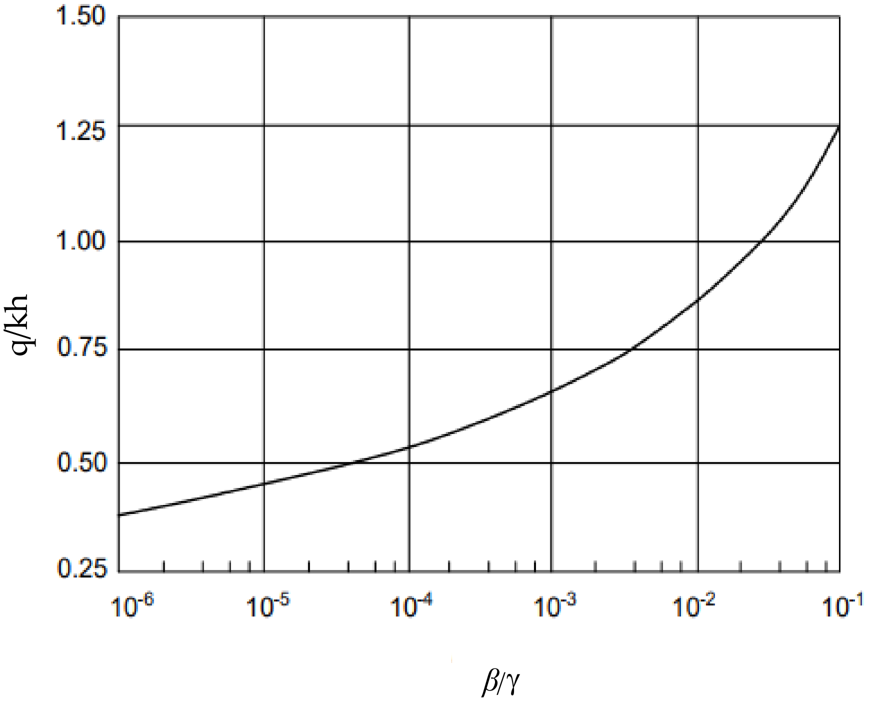


FIG. 7 SEEPAGE DISCHARGE *q/kh*

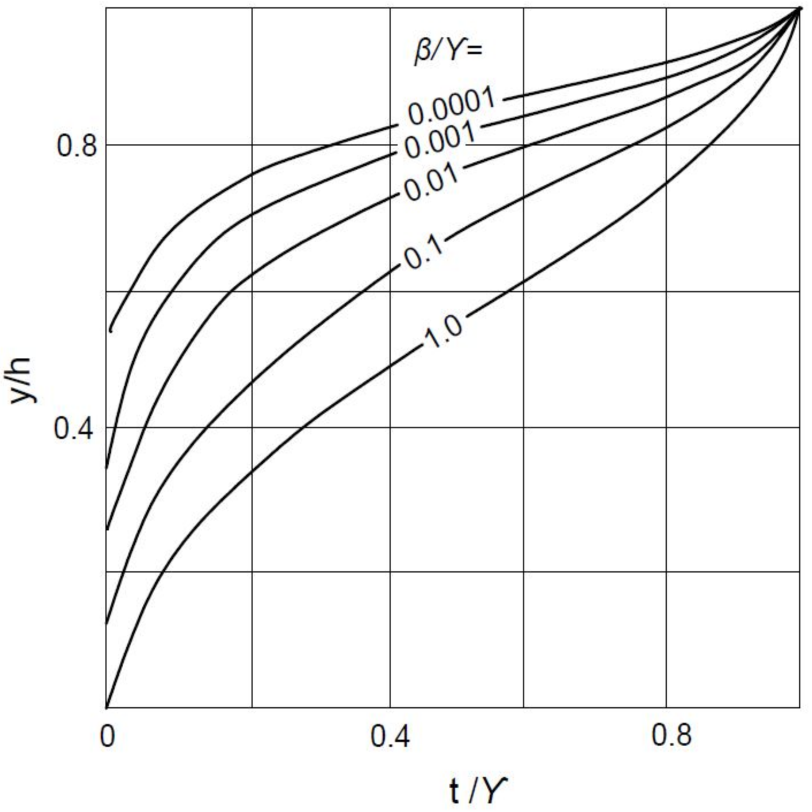


FIG. 8 ORDINATES OF FREE SURFACE

5.2 Canals Located in Medium Extending Up to Finite Depth with Shallow Water Table

Among the various methods in vogue, closed form method which is generally adopted is given below.

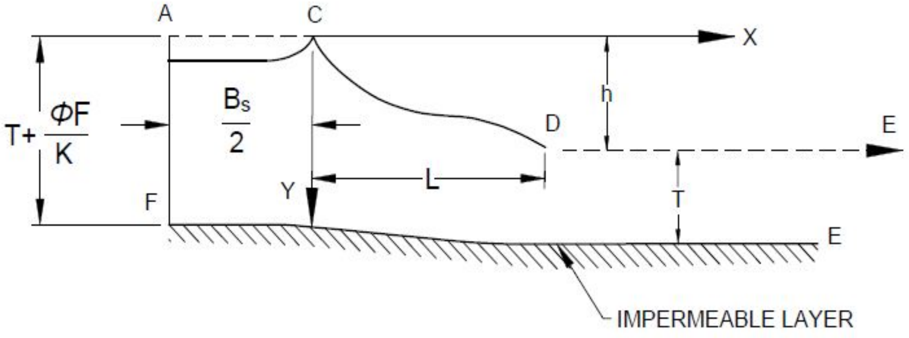
5.2.1 The procedure for determining the seepage discharge for the canal for horizontal and vertical drainage conditions (*see* Fig. 9) is given below.

5.2.2 *Seepage Discharge*

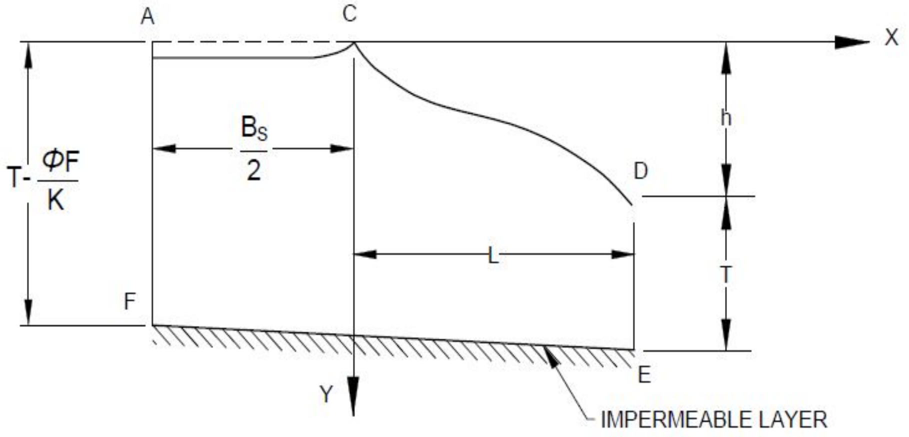
Knowing the dimensions of the system in the physical plane, the two parameters σ and β are determined from Figs. 10 and 11 for horizontal and vertical drainage conditions respectively. Figures 12 and 13 are used for determining non–dimensional seepage discharge *q/kh* for horizontal and vertical drainage conditions respectively.

5.2.3 *Phreatic Surface*

Figures 14 and 15 can be used parametrically to obtain *x* and *y* coordinates of the phreatic surface. For the known values of σ and σ/β the coordinates of phreatic surface can be obtained from these figures. The phreatic surfaces have been plotted for = 10^{-4}, 10^{-10}, 10^{-20}, 10^{-30} and σ/β ranging between 10^{-2} to 10^{2}.



(A) Horizontal drainage



(B) Vertical drainage

FIG. 9 PHYSICAL PLANES OF DRAINAGES

5.3 Canals Located in Medium Extending Up to Infinite Depth with Deep Water Table

The solution for this boundary condition was obtained by Vedernikov with the help of conformal mapping. The seepage discharge, q per unit length of channel is given by

$$q = kB + (A + 2m)H$$

$$= k(B_s + AH)$$

The value of A is obtained from Fig. 16 for the known values of B/H or B_s/H and m.

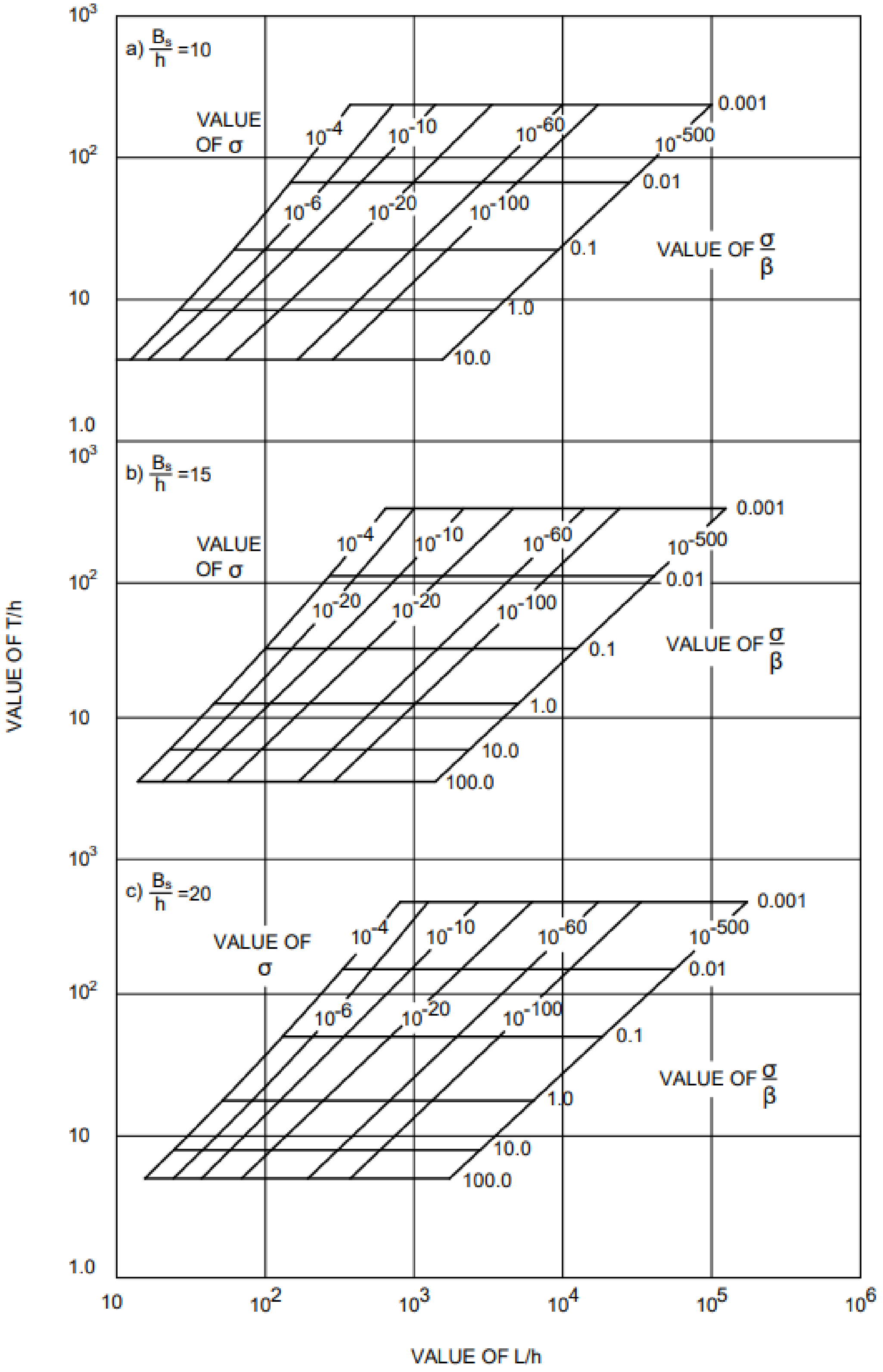


FIG. 10 RALATION BETWEEN *L/h, T/h,* σ AND β (HORIZONTAL DRAINAGE)

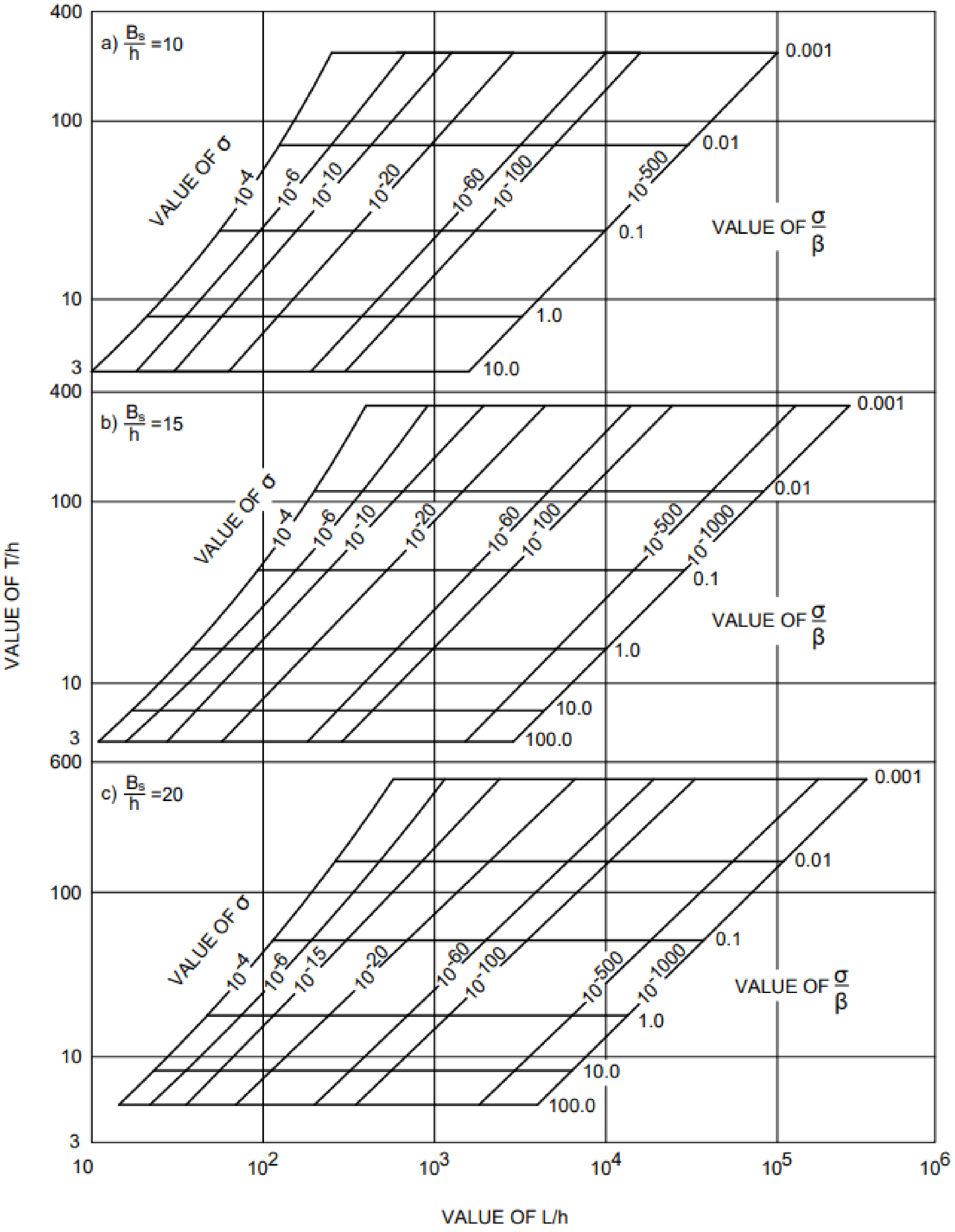


FIG. 11 RELATION BETWEEN L/h, T/h, σ AND β (VERTICAL DRAINAGE)

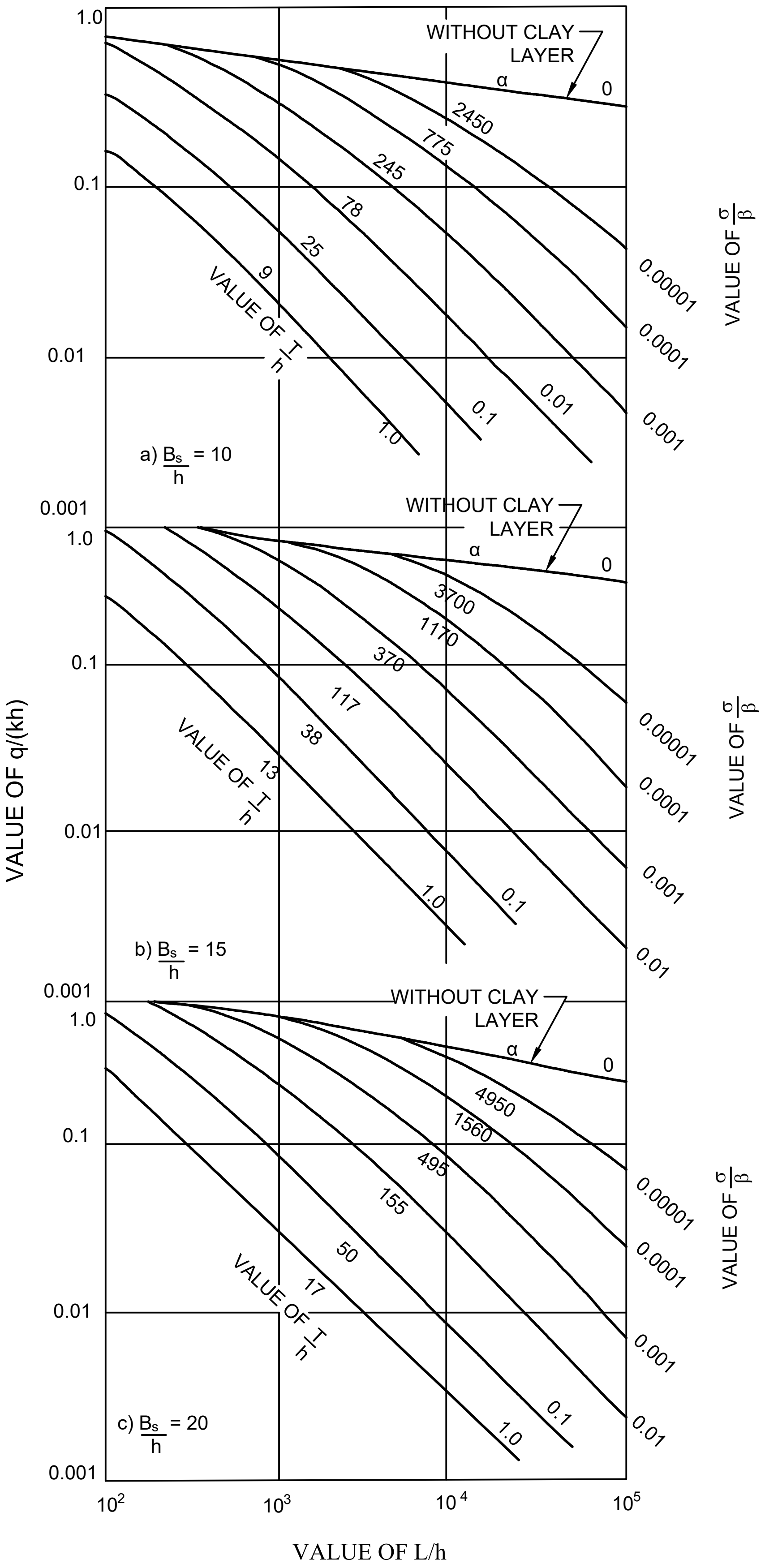


FIG 12. SEEPAGE DISCHARGE (HORIZONTAL DRAINAGE)

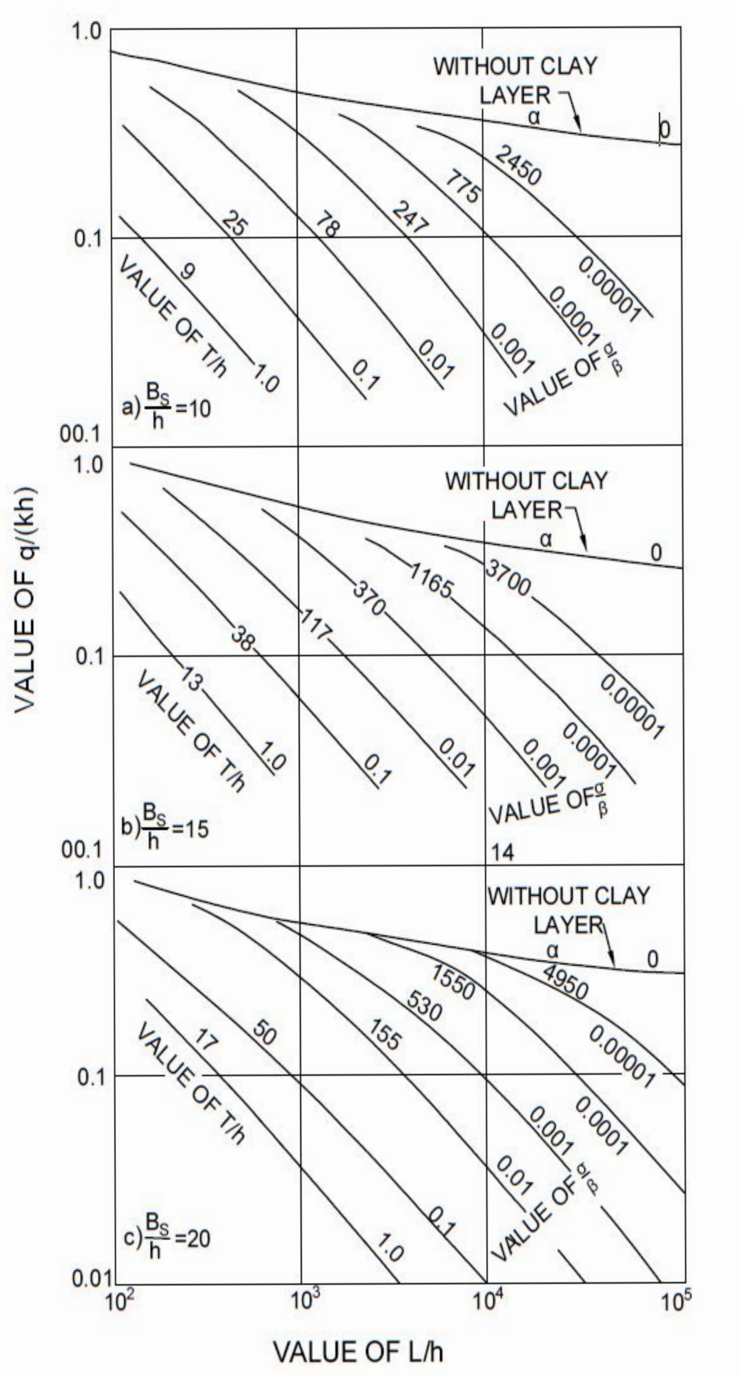


FIG. 13 SEEPAGE DISCHARE (VERTICAL DRAINAGE)

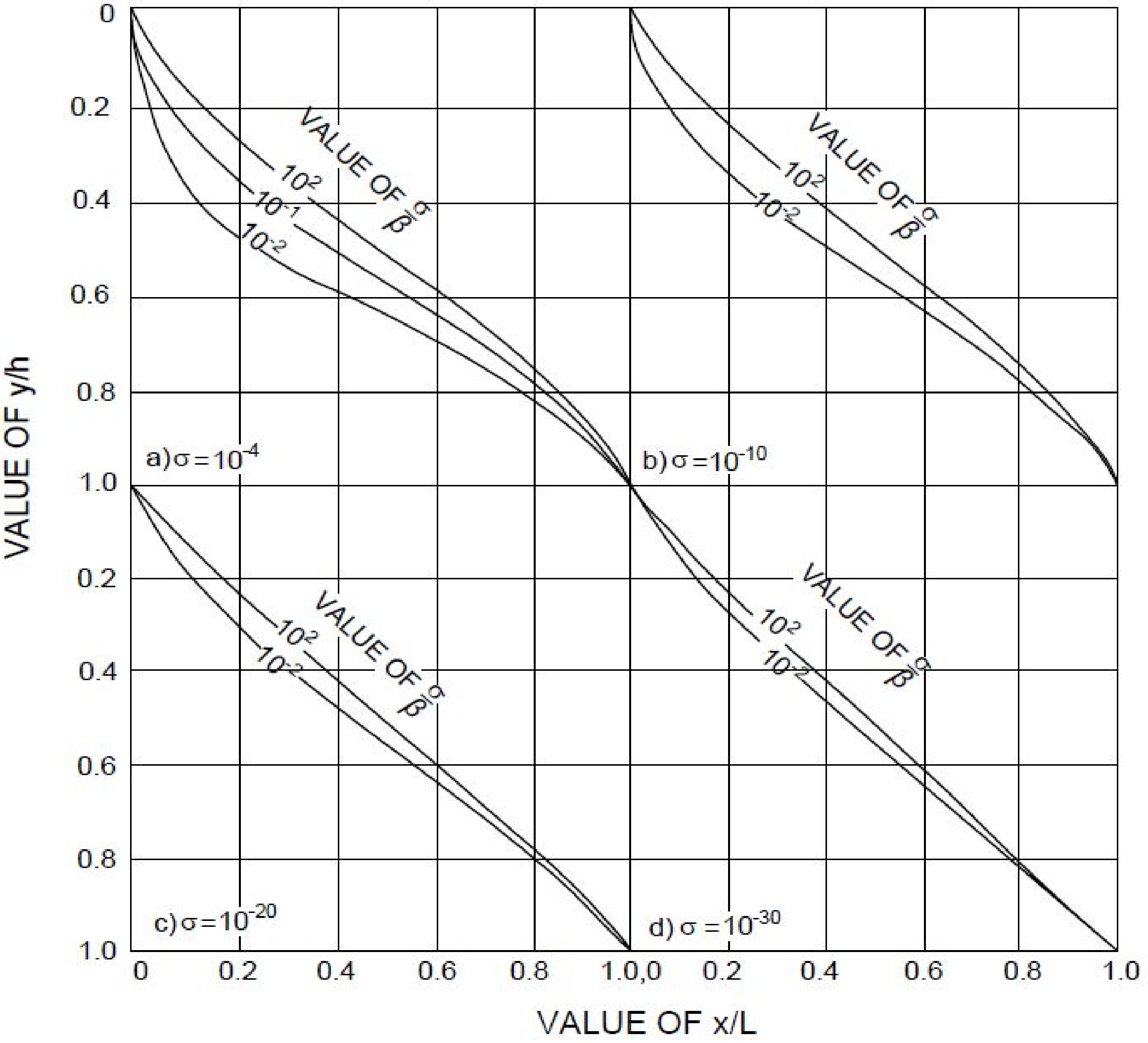


FIG. 14 COORDINATES OF PHREATIC SURFACE (HORIZONTAL DRAINAGE)

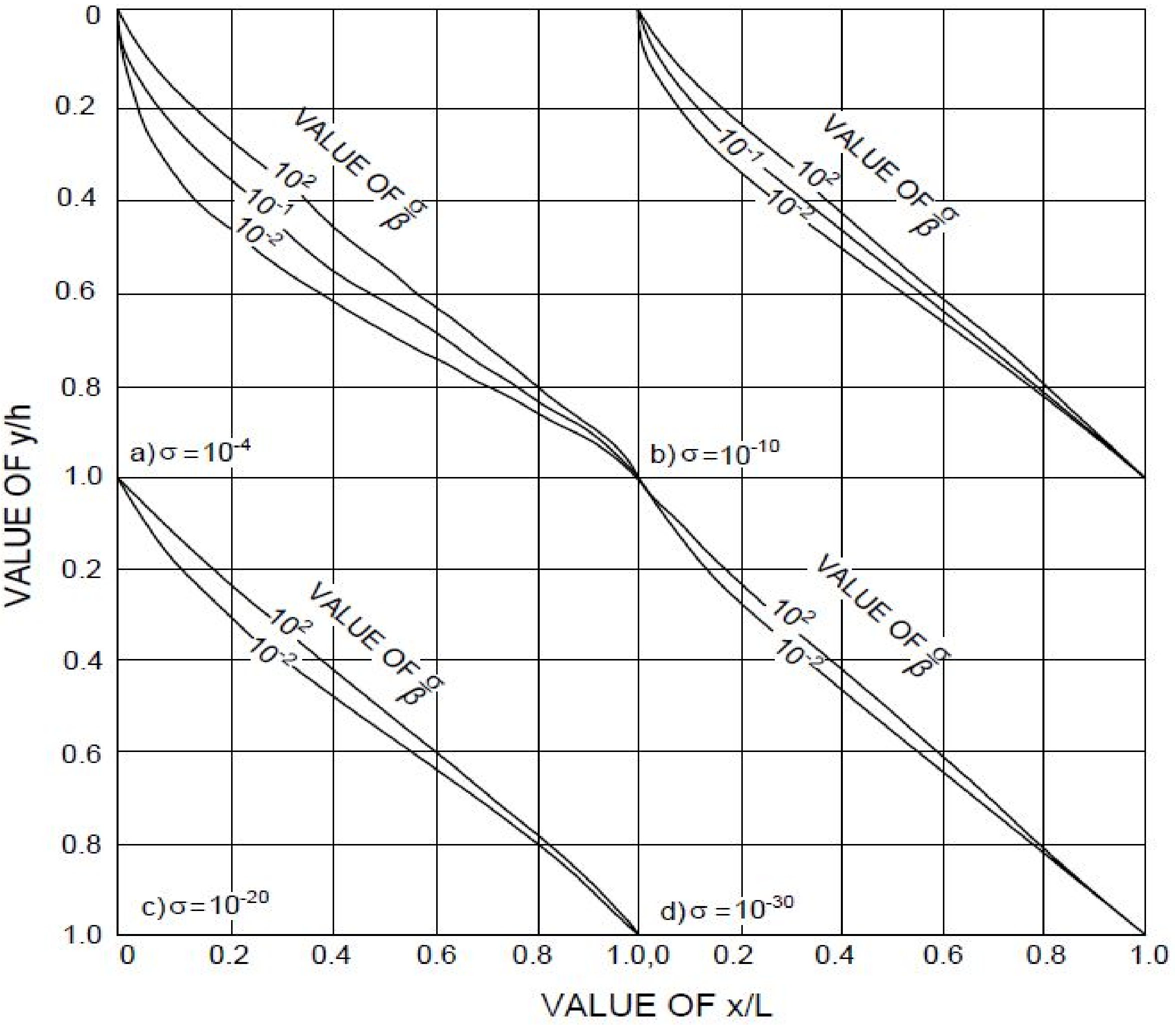


FIG. 15 COORDINATES OF PHREATIC SURFACE (VERTICAL DRAINAGE)

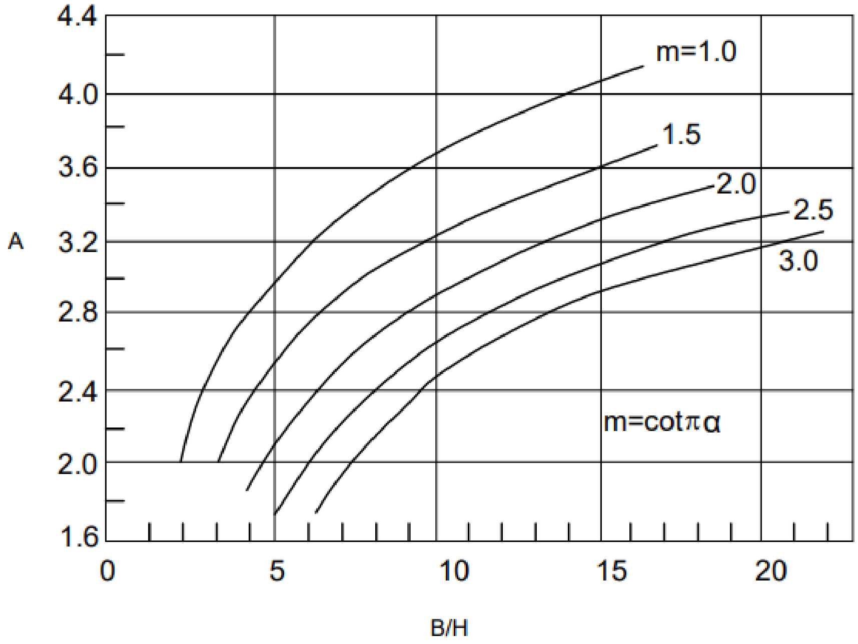


FIG. 16 VALUE OF A

6 LIMITATIONS

The drainage conditions on either side of the canal are assumed to be symmetrical and these may be different in practice. The seepage losses and phreatic surface for both the sides are determined separately assuming that the dividing line is vertical through the center of the canal.

7 EXAMPLE

An illustrative example for cases given in **3.2**(a), **3.2**(b) and **3.2**(c) is provided in Annex A.

ANNEX A

(*Clause* 7.1)

EXAMPLE FOR CASES GIVEN IN 3.2(a), 3.2(b) AND 3.2(c)

Following are the physical dimensions of a canal for which seepage discharge and free surface on either side are to be determined (Fig. 17):

a)	Bed width	$B = 68.8$
b)	Water depth	$H = 3.44\ m$
c)	Side slop angle	$0.147\ 77\ \pi$

Right side of channel

a)	Drainage distance	$L = 5\ 300\ m$
b)	Difference in channel and drainage Water level	$h = 7.25\ m$

Left side of channel

a)	Drainage distance	$L = 10\ 600\ m$
b)	Difference in channel and drainage Water level	$h = 8.4\ m$

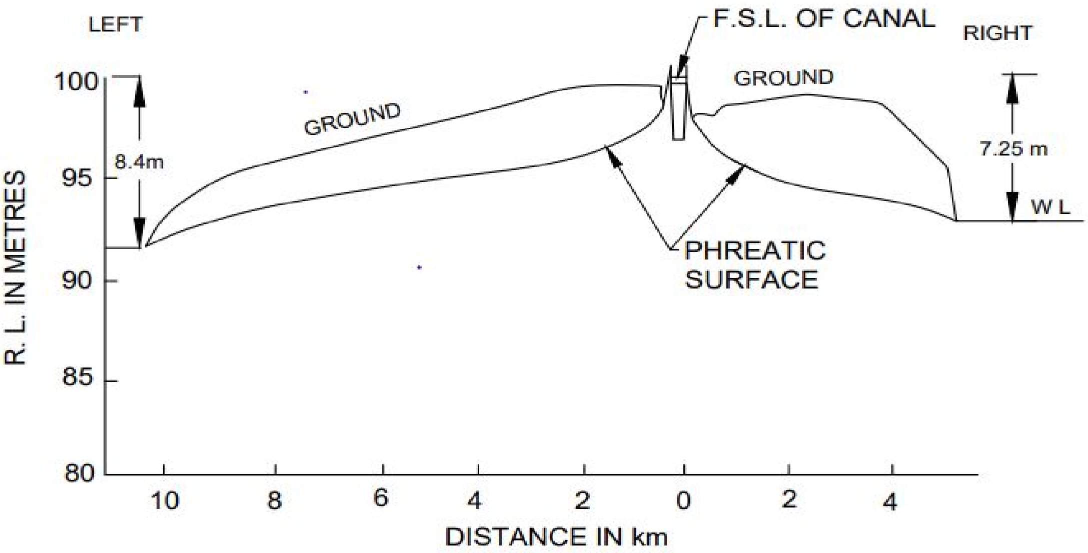


FIG. 17 CROSS SECTION SHOWING PHREATIC SURFACE

For the case corresponding to **3.2** (a) the seepage losses are determined as follows:

Horizontal Drainage: For values of α, *B/H*, *L/H* equal to 0.147 77, 20.0 and 1 540 respectively for the right-side Fig. 3, Fig. 5 and Fig. 6 yield the values of $\beta = 3.5$ and $\gamma = 5.0 \times 10^4$. For these values of β and γ, the non-dimensional seepage loss *q/kh* is obtained from Fig. 7 as 0.52. Similarly, the values of β and γ for the left side are obtained as 3.7 and 2.3×10^5 respectively. The value of non-dimensional seepage discharge *q/kh* from Fig. 7 is obtained as 0.47. Taking as average value of coefficient of permeability equal to 2.5×10^{-5} m/s, the seepage losses are obtained out as 0.094 m3/sec/km and 0.099 m^3/s/km considering the right and left sides boundary condition respectively. The average value of seepage losses is computed as 0.096 5 m^3/s/km.

Vertical Drainage: For value of α, *b/H*, *L/H* equal to 0.147 77, 20.0 and 1540 respectively for the right side, Fig. 4, Fig. 5 and Fig. 6 yield the values of $\beta = 3.5$ and $\gamma = 2 \text{ X } 10^4$. For these values of β and γ, the non-dimensional seepage loss q / kh is obtained from Fig. 7 as 0.55. Similarly, the values of β and γ for the left side are obtained as 0.48. For average value of coefficient of permeability equal to $2.5 \text{ X } 10^{-5}$ m/s the seepage losses as obtained equal to 0.099 m^3/s/km and 0.100 m^3/s/km respectively considering the right and left sides boundary conditions respectively. The average value of seepage losses is determined as 0.100 m^3/s/km.

For the case corresponding to **3.2**(b) when the canal is assumed to be located in medium underlain by an impervious layer at a depth of 100 m, the non-dimensional seepage discharge q / kh is obtained from Fig. 12 as 0.055 and 0.019 0 respectively for the right and left sides respectively for horizontal drainage. Similarly, the non-dimensional seepage discharges, *q/kh* values for vertical drainage case from Fig. 12 are 0.06 and 0.02 respectively. The average seepage discharge values are computed as 0.007 1 m^3/s/km and 0.007 5 m^3/s/km for the horizontal and vertical drainage conditions respectively. It is seen that these values are less than those obtained with infinite depth of permeable stratum.

For the case corresponding to **3.2** (c) when the canal is underlain by deep water table the seepage loss is computed 2.37 m^3/s/km, which is very high compared to the values obtained for the above-said conditions **3.2**(a) and **3.2**(b).

ANNEX B

(*Foreword*)

COMMITTEE COMPOSITION

Canals and Cross Drainage Works Sectional Committee, WRD 13

Organization	*Representative(s)*
Central Water Commission, New Delhi	Shri S. K. Sibal Chief Engineer Design (N & W) (***Chairperson***)
Bhakra Beas Management Board, Punjab	Director Design Superintending Engineer (*Alternate*)
Brahmaputra Board, Guwahati	Shri Gaya Prasad Singh Shri Shyamal Kr Deka (*Alternate*)
Central Board of Irrigation & Power, New Delhi	Dr G. P. Patel Director (Wr) Shri Sunil Sharma Chief Manager (*Alternate*)
Central Soil and Materials Research Station, New Delhi	Shri N. V. Mahure Sc E Shri Shahid Noor Sc D (*Alternate*)
Central Water & Power Research Station, Pune	Dr Neena Isaac Sc E Shri Suresh Kumar Sc C (*Alternate* I) Shri Arun Kumar Sc C (*Alternate* II)
Central Water Commission, New Delhi	Shri Manoj Kumar Meena Director Shri S. K. Shukla Director Bcd (E&Ne) (*Alternate*)
Department of Water Resources, Punjab	Shri H. S. Mendiratta Director (Canals) Executive Engineer Rc Cdo (*Alternate*)
Indian Institute Of Technology Roorkee, Roorkee	Prof Manoj Kumar Jain Prof S. K. Singal (*Alternate*)
Indian Institute Of Technology, Delhi	Dr B. R. Chahar
Irrigation & Water Resources Department, Haryana	Shri Sandeep Taneja Shri Pradeep Yadav(*Alternate*)
Irrigation & Water Resources Department, Ministry of Jal Shakti Govt. of Uttar Pradesh	Shri Rakesh Kumar Gupta Shri Upendra Nath Kumar (*Alternate*)
Irrigation Department, Government of Kerala	Chief Engineetr Irrigation Shri Manju Balakrishna (*Alternate*)
Irrigation Research Institute, Roorkee	Shri Dinesh Chandra, C. E. Level - 1 Shri Naveen Singhal, S. E. (*Alternate*)
Narmada Water Resources, Water Supply and Kalpasar Dept, Gandhinagar	Shri A. M. Barve Director Shri B. H. Chaudhary S. E. (*Alternate* I) Shri P. V. Vyas S. E. (*Alternate* II)

NHPC Ltd., Faridabad(I)	SHRI SHRISH DUBEY GM (CIVIL) SHRI PRSHANTH JAISWAL DGM (CIVIL) (*Alternate* I) SHRI DEEPAK VERMA DM (CIVIL) (*Alternate* II)
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WAPCOS Limited, Gurgaon	SHRI SHAMBHU AZAD SHRI A. K. GEHLOT (*Alternate*)
Water Resources Department, Andhra Pradesh	SHRI A. SURI BABU SUPERINTENDING ENGINEER (CANAL) (*Alternate)*
Water Resources Department, Bihar	SUPERINTENDING ENGINEER (GATES)
Water Resources Department, Chhattisgarh	SHRI R. K. NAGARIA SHRI U. R. RATHOR ASSISTANT ENGG (*Alternate*)
Water Resources Department, Rajasthan	CHIEF ENGINEER (ID & R) DIRECTOR (CANALS ID & R) (*Alternate*)
Water Resources Department, Maharashtra	SHRI RAJENDRA PAWAR SHRI M. M. PARATE S. E (*Alternate*)
Water Resources Department, Madhya Pradesh	SHRI V. K. WASHIK SHRI BHAGWATI PRASAD GUPTA (*Alternate*)
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In Personal Capacity (*204, Raj Mahal Apartments, Devi Marg, Bani Park, Jaipur – 302016*)	SHRI Y. C. AGRAWAL
BIS Directorate General	SHRI R. BHANU PRAKASH SCIENTIST 'E'/DIRECTOR AND HEAD (WATER RESOURCES DEPARTMENT) [REPRESENTING DIRECTOR GENERAL (*Ex-officio*)]

Member Secretary
SHRI DUSHYANT PRAJAPATI
SCIENTIST 'D'/JOINT DIRECTOR
(WATER RESOURCES DEPARTMENT), BIS

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This Indian Standard has been developed from Doc No.: WRD 13 (17627).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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